EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/83-113

11 August, 1983

**$\bar{p}p$ ELASTIC SCATTERING AT 30 GeV/c INCIDENT MOMENTUM
IN THE MOMENTUM TRANSFER RANGE $0.5 < -t < 5.8$ (GeV/c)²**

Z. Asa'd^f, C. Baglin^a, R. Bock^b, J.M. Brom,¹
L. Bugge^{b,e}, T. Buran^e, A. Buzzo^d, M. Coupland^f, D.G. Davis^f,
B.G. Duff^f, T. Fearnley^{e,f}, S. Ferroni^d, I. Kenyon Gjerpe^{b,f}, J.P. Guillaud^a,
V. Gracco^d, F.F. Heymann^f, D.C. Imrie^f, E. Khan,²
K. Kirsebom^e, A. Lundby^b, G.J. Lush^f, M. Macri^d, J. Myrheim^{c,3},
M. Phillips^f, M. Poulet^a, L. Rossi^d, A. Santroni^d, G. Skjevling^e, S.O. Sorensen^e.

Annecy (LAPP)^a - CERN^b - Copenhagen (Niels Bohr Institute)^c - Genova^d -
- Oslo^e - University College London^f Collaboration

ABSTRACT

The $\bar{p}p$ elastic differential cross section at 30 GeV/c incident momentum has been measured in a two-arm spectrometer experiment (WA7) at the CERN SPS. The $|t|$ -range covered extends from 0.5 to 5.8 (GeV/c)². A pronounced dip-bump structure is observed, with a sharp minimum around $|t| \approx 1.7$ (GeV/c)². The results are compared with existing $\bar{p}p$ data at lower energies and with our earlier $\bar{p}p$ data at 50 GeV/c. A number of model predictions are discussed. We also compare the $\bar{p}p$ 30 GeV/c differential cross section with that of pp at the same momentum. Finally, the energy dependence of the $\bar{p}p$ fixed- $|t|$ differential cross section in the incident momentum range 3.6 to 50 GeV/c is presented.

(Submitted to Physics Letters B)

¹ University of Strasbourg

² present address CERN EP

³ present address NORDITA, Copenhagen

A measurement of the $\bar{p}p$ 30 GeV/c elastic differential cross section in the momentum transfer range $0.5 < |t| < 5.8$ (GeV/c)² is presented. The experiment was part of a programme at the CERN SPS, in which hadron-proton elastic scattering was measured over a wide range of momentum transfers and beam momenta. Results on $\pi^{\pm}p$ elastic scattering at very large angles at 20 and 30 GeV/c [1], $\bar{p}p$ elastic scattering at 50 GeV/c for $0.7 < |t| < 5.0$ (GeV/c)² [2], and $\pi^{\pm}p$ [3] and $K^{\pm}p$ [4] elastic scattering at 20 and 50 GeV/c for $0.7 < |t| < 8.0$ (GeV/c)² have already been published. A recent measurement of the pp 50 GeV/c elastic differential cross section for $0.8 < |t| < 4.0$ (GeV/c)² will soon be published [5]. This experiment is the first to measure $\bar{p}p$ elastic scattering between 10 and 50 GeV/c over a wide $|t|$ -range. Previous $\bar{p}p$ data in this energy interval are limited to $|t| < 1.3$ (GeV/c)² [6-8].

The apparatus, shown schematically in Fig.1, consisted of a double-arm spectrometer downstream of a liquid hydrogen target, upon which an unseparated beam of high intensity ($\approx 2 \times 10^7$ ppb) was incident. The beam contained $\approx 2\%$ antiprotons. The beam particles were detected by a beam hodoscope consisting of three planes, each containing 40 scintillators 2mm wide. A differential Cerenkov counter (CEDAR1) on the beam line was used to identify the incident antiprotons. The scattered particles were detected by counter hodoscopes (H1,PR1 and H2,PR2) and multiwire proportional chambers (MWPCs) in each arm, and by Cerenkov counters in the forward arm. The trigger imposed rough geometrical and kinematic constraints by means of hodoscope matrix correlations, incident beam signature requirements, and an energy threshold requirement for the forward scattered particles, imposed by an iron/scintillator-sandwich calorimeter. Veto counters surrounding the target were used to eliminate multi-particle events with tracks outside the geometrical acceptance of the experiment. Multiplicity constraints in the hodoscopes reduced multi-particle inelastic events. The momentum of the forward scattered particles was determined with a precision of $\pm 10\%$ by a spectrometer magnet with an integrated field of 1.8Tm. The scattered particle trajectories were determined by nine MWPCs (CH0-CH9) with a total of 35 wire planes. Particle identification in the forward arm was provided by two threshold Cerenkov counters (C1 and C2) at atmospheric pressures. C1 was filled with a N₂/He gas mixture, yielding the thresholds 9, 32.5 and 60 GeV/c for π^- , K^- and $\bar{p}$, respectively. The corresponding thresholds for C2, filled with CO₂, were 5, 17.5 and 33 GeV/c.

1.9×10^6 triggers were analysed. The off-line analysis provided forward- and recoil-arm track reconstruction from the MWPC digitizings, and beam position determination from the beam hodoscope information. 3-prong vertices passing

rough kinematic cuts were then fitted, using Runge-Kutta tracking through the magnetic field and applying elastic kinematic constraints. The event selection was based on the $\chi^2/\text{degree of freedom (dof)}$ of the fit, and the best vertex from each trigger was selected.

The background estimate was based on the resulting χ^2/dof distributions for each t -bin. A consistency check was provided by the coplanarity and $\Delta\theta$ distributions, the latter being the difference between the measured forward scattering-angle and the one expected for an elastic event given the measured recoil scattering-angle. For each t -bin, the number of elastic events was extracted by introducing a χ^2 -cut, and subtracting the background extrapolated from above the cut. Clear elastic signals were seen in all t -bins, except in the dip region. Depending on $|t|$ -bin, background accounted for 3-20% of all events below the cut, with the exception of the dip region ($1.5 < |t| < 1.8 \text{ (GeV/c)}^2$) which contained $\approx 50\%$ background. A total of 12429 events survived the χ^2 -cuts, and 11870 elastic events were obtained after subtracting background.

The data have been corrected for angular dependent MWPC track-reconstruction efficiency and geometrical acceptance of the apparatus. Global corrections applied include random multiplicity veto, beam hodoscope efficiency, calorimeter loss, livetime, target absorption of incident beam particles, and interactions in the beam hodoscope. The overall normalization error is estimated to be less than 20%.

The $\bar{p}p$ 30 GeV/c elastic differential cross section is shown in Fig.2, together with the $\bar{p}p$ 50 GeV/c cross section of ref.2. A prominent dip around $|t| \approx 1.7 \text{ (GeV/c)}^2$ is observed at 30 GeV/c, as compared to the equally prominent dip around $|t| \approx 1.5 \text{ (GeV/c)}^2$ at 50 GeV/c. Our data thus show that the dip moves towards lower $|t|$ -values as the energy increases. At both energies, the dip is followed by a pronounced second maximum and a subsequent fall-off in $|t|$. The $\bar{p}p$ 30 GeV/c data also indicate a change of slope around $|t| \approx 0.8 \text{ (GeV/c)}^2$.

Fig.3 [2,9-11] includes a comparison with lower energy $\bar{p}p$ data (5 to 10 GeV/c). It is seen that the structure around $|t| \approx 0.5 \text{ (GeV/c)}^2$ in the low energy data has disappeared in the 30 and 50 GeV/c data, leaving only a change of slope. Moreover, the inward dip movement observed when increasing the energy from 30 to 50 GeV/c naturally associates the prominent dip at these energies with the structure around $|t| \approx 2 \text{ (GeV/c)}^2$ seen at 10 GeV/c [11]. One

is thus led to conclude that the dip must develop rapidly between 10 and 30 GeV/c, and, during this process, move towards smaller $|t|$ -values as energy is increased.

Such a dip movement is in sharp disagreement with predictions by the geometrical model of Chou and Yang [12], in which the dip at $|t| \approx 1.5$ (GeV/c)² in the $\bar{p}p$ 50 GeV/c cross section is associated with the low- $|t|$ structure around $|t| \approx 0.5$ (GeV/c)² seen at lower energies (Fig.3). Chou and Yang thus concluded that the dip moves towards larger $|t|$ with increasing energy, and predicted a dip around $|t| \approx 1.1$ (GeV/c)² in the 30 GeV/c cross section. It is clear that this prediction is inconsistent with our $\bar{p}p$ data.

Recently, Kroll has tested the Geometrical Scaling (GS) model using the $\bar{p}p$ 50 GeV/c data of ref.2, and finds that GS works well at this energy [13]. It is therefore natural to ask if the GS prediction for $\bar{p}p$ 30 GeV/c is consistent with our data. GS predicts a dip movement according to $-t_{\text{dip}} \sim 1/\sigma_{\text{tot}}$. Since for $\bar{p}p$ σ_{tot} is larger at 30 GeV/c than at 50 GeV/c, GS would lead to a dip in the 30 GeV/c cross section at a smaller $|t|$ -value than at 50 GeV/c. This result disagrees with our data. Of course, 30 GeV may be too low an energy to expect a simple GS behaviour.

In the nucleon core model of Islam et al. [14,15], the dip is interpreted as a destructive interference between a diffractive and a hard scattering amplitude. The model indicates [14] that the $\bar{p}p$ dip at 50 GeV/c should be associated with the low-energy structure around $|t| \approx 2$ (GeV/c)² (Fig.3). It thus correctly leads to the observed inward dip movement with increasing energy. Using a set of diffraction parameters (with hard scattering parameters fixed by pp elastic scattering), the model can reproduce the overall behaviour of the 30 GeV/c angular distribution (Fig.2).

In the recent model of Donnachie and Landshoff [16], high energy pp and $\bar{p}p$ elastic scattering are described in terms of single and double Pomeron and triple gluon exchanges. At lower energies ($p_{\text{lab}} \leq 50$ GeV/c), additional Regge-Pomeron contributions are needed to reproduce the dip in the $\bar{p}p$ data. In this model, the low energy $\bar{p}p$ dip therefore originates from a different process than the pp dip at ISR energies.

Fermilab $\bar{p}p$ data at 100 and 200 GeV/c [17] indicate that the dip persists to higher energies. The dip position is uncertain due to poor statistics, but data point towards little or no dip movement between 50 and 200 GeV/c. Preliminary

results from the CERN $\bar{p}p$ collider indicate that the dip has disappeared at $\sqrt{s}=540$ GeV [18]. At this energy, the differential cross section features an abrupt change of slope around $|t|\approx 0.8$ (GeV/c)², followed by a shoulder. $\bar{p}p$ measurements at ISR energies are needed to investigate the dip development in the intermediate energy region.

Fig.4 shows a comparison between $\bar{p}p$ (this exp.) and pp [19] elastic differential cross sections at 30 GeV/c. While the cross sections almost overlap at low $|t|$, a major difference is seen in the dip region where the pp cross section features only a break around $|t|\approx 1.4$ (GeV/c)². Moreover, this break appears to coincide with a change of slope in the $\bar{p}p$ cross section, associated with the dip. High- $|t|$ pp data at 30 GeV/c are scarce, but a measurement at $|t|=6$ (GeV/c)² [19] indicates that the pp and $\bar{p}p$ cross sections are comparable here.

The energy dependence of the $\bar{p}p$ elastic differential cross sections between 3.6 and 50 GeV/c at fixed $|t|$ -values of 2.0 and 4.0 (GeV/c)² is shown in Fig.5 [2,9-11,21,22]. Parametrizing the differential cross section at fixed $|t|$ as

$$d\sigma/dt \sim p_{lab}^{-\alpha},$$

we find $\alpha\approx 2.5$ for $|t|=2$ (GeV/c)², and $\alpha\approx 1.6$ for $|t|=4$ (GeV/c)². This energy dependence differs from what we find for pp scattering in the same energy range [5], where $\alpha_{pp}(t)$ is found to increase roughly linearly with $|t|$ according to $\alpha_{pp}(t) \approx 0.6|t|+0.7$.

We wish to thank Professor M.M Islam for his valuable comments on the paper. We gratefully acknowledge the technical assistance of P. Anzoli, R.M. Audria, G. Barisone, R. Kiesler, J.C. Lacotte, B. Mouellic, P. Mugnier, F. Nordby, D. Ploujoux, P. Poggi, R.H. Watson, D.B. Webb, the SPS experimental support group, the DD on-line support group, the EP electronics group, and financial support from the UK Science and Engineering Research Council, the Danish National Science Research Council, the French National Centre for Scientific Research, the Italian Istituto Nazionale di Fisica Nucleare, and the Norwegian Research Council for Science and Humanities.

References

- 1) R. Almas et al., Phys.Lett.93B (1980) 199.
C. Baglin et al., Nucl.Phys.B216 (1983) 1.
- 2) Z. Asa'd et al., Phys.Lett.108B (1982) 51.
- 3) Z. Asa'd et al., Phys.Lett.118B (1982) 442.
- 4) Z. Asa'd et al., Phys.Lett.123B (1983) 265.
- 5) Z. Asa'd et al., CERN-EP/83-68 (1983) (to be published in Phys.Lett.B).
- 6) D. Birnbaum et al., Phys.Rev.Lett.23 (1969) 663.
- 7) Y.M. Antipov et al., Nucl.Phys.B57 (1973) 333.
- 8) C. Bruneton et al., Nucl.Phys.B124 (1977) 391.
- 9) A. Eide et al., Nucl.Phys.B60 (1973) 173.
- 10) T. Buran et al., Nucl.Phys.B97 (1975) 11.
- 11) A. Berglund et al., Nucl.Phys.B176 (1980) 346.
- 12) T.T. Chou and C.N. Yang, Phys.Rev.Lett.46 (1981) 764.
- 13) P. Kroll, Z.Phys.C15 (1982) 67.
- 14) G.W. Heines and M.M. Islam, Nuovo Cimento 61A (1981) 149.
J.P. Guillaud and M.M. Islam, University of Connecticut Preprint
80-0861 (1980).
- 15) M.M. Islam, T. Fearnley and J.P. Guillaud, CERN-EP/83-96 (1983).
- 16) A. Donnachie and P.V. Landshoff, Univ. of Cambridge Preprint
DAMTP 83/9 (1983).
A. Donnachie and P.V. Landshoff, Phys.Lett.123B (1983) 345.
- 17) D.H. Kaplan et al., Phys.Rev.D26 (1982) 723.
- 18) J. Timmermans, XVIII Rencontre de Moriond (March 1983).
M. Bozzo et al., Contribution to the International Conference on
High Energy Physics, Brighton (July 1983).
- 19) R.M. Edelstein et al., Phys.Rev.D5 (1972) 1073.
G. Cocconi et al., Phys.Rev.B138 (1965) 165.
- 20) E. Nagy et al., Nucl.Phys.B150 (1979) 221.
- 21) W.M. Katz, B. Forman and T. Ferbel, Phys.Rev.Lett.19 (1967) 265.
- 22) D.P. Owen et al., Phys.Rev.181 (1969) 1794.

Figure Captions

- Fig. 1 Schematic view of the apparatus.
- Fig. 2 $\bar{p}p$ elastic differential cross section at 30 GeV/c incident momentum (this exp.), compared with the $\bar{p}p$ 50 GeV/c data of ref.2. Solid curve is the theoretical $\bar{p}p$ 30 GeV/c elastic differential cross section calculated in the nucleon core model [15].
- Fig. 3 $\bar{p}p$ elastic differential cross section at 30 GeV/c (this exp.), compared with $\bar{p}p$ data at 5.0 [9], 6.2 [10], 10.1 [11] and 50 [2] GeV/c. The data from refs. 9 and 10 are presented as smoothed curves.
- Fig. 4 $\bar{p}p$ elastic differential cross section at 30 GeV/c (this exp.), compared with pp 30 GeV/c data of ref.19 (the large- $|t|$ data point is from Cocconi et al.).
- Fig. 5 Energy dependence of $\bar{p}p$ elastic differential cross sections at fixed $|t|$ -values of 2.0 and 4.0 (GeV/c)². The straight lines are eye-fits through data points at 3.6 GeV/c [21], 5.0 GeV/c [9], 5.8 GeV/c [22], 6.2 GeV/c [10], 9.7 GeV/c [22], 10.1 GeV/c [11], 30 GeV/c (this exp.) and 50 GeV/c [2].

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5